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U.S. APPLICATION NUMBER

097/647676

INTERNATIONAL APPLICATION NO.

PCT/JP99/00476 ✓

INTERNATIONAL FILING DATE

04 February 1999 (04.02.99) ✓

PRIORITY DATE CLAIMED

TITLE OF INVENTION: **IP KEY MANAGEMENT MECHANISM WITH DIVERGENCE BARRIER**
INCREASING ENTROPY AGAINST COMPUTATIONAL CRYPTO-ANALYSES ✓APPLICANT(S) FOR DO/EO/US: **WATANABAE, Eiichi** ✓

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☐ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
 - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☒ has been transmitted by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
 - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☐ have been transmitted by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☐ A **FIRST** preliminary amendment.
☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
14. ☐ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information:

PCT Request; PCT International Search Report; Specification (12 pages); Claims (3 pages); Formal Drawings (7 pages)

U.S. APPLICATION NO. 09/647676		INTERNATIONAL APPLICATION NO. PCT/JP99/00476		ATTORNEY'S DOCKET NO. 000004.00662	
17. <input checked="" type="checkbox"/> The following fees are submitted: BASIC NATIONAL FEE (37 CFR 1.492(a)(1)-(5)): Search Report has been prepared by the EPO or JPO \$840.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) \$670.00 No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) \$970.00 Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO \$670.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) \$ 96.00 ENTER APPROPRIATE BASIC FEE AMOUNT =				CALCULATIONS PTO USE ONLY	
Surcharge of \$130.00 for furnishing the oath or declaration later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				\$ 840.00	
				\$	
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total Claims	10 - 20 = 0		X \$22.00	\$ 0	
Independent Claims	1 - 3 = 0		X \$80.00	\$ 0	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ \$260.00	\$ 0	
TOTAL OF ABOVE CALCULATIONS =				\$ 840.00	
Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28).					
SUBTOTAL =				\$ 840.00	
Processing fee of \$130.00 for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(i)).				+	\$
TOTAL NATIONAL FEE =				\$ 840.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property				+	\$ 40.00
TOTAL FEES ENCLOSED =				880.00	
				Amount to be refunded:	
				charged:	\$
a. <input checked="" type="checkbox"/> A check in the amount of \$ <u>880.00</u> to cover the above fees is enclosed. b. <input type="checkbox"/> Please charge my Deposit Account No. _____ in the amount of \$ _____ to cover the above fees. A duplicate copy of this sheet is enclosed. c. <input checked="" type="checkbox"/> The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. <u>23-2185</u> (000004.00662). A duplicate copy of this sheet is enclosed.					
NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.					
<i>Michael D. White</i> Signature: _____ _____ NAME					
SEND ALL CORRESPONDENCE TO: Customer No.: 002779 BLANK ROME COMISKY & McCaULEY LLP 900 - 17th Street, N.W., Ste. 1000 Washington, D.C. 20006					
32.795 / October 3, 2000 Registration No. / Date					

DESCRIPTION

IP KEY MANAGEMENT MECHANISM
WITH DIVERGENCE BARRIER INCREASING ENTROPY
AGAINST COMPUTATIONAL CRYPTO-ANALYSES

Technical Field

The present invention relates to an IP (internet protocol) key management mechanism for an internet security architecture.

More specifically, the invention relates to a key management mechanism for an IP-layer security, as a component mechanism of a security architecture for internets, in which a crypt-system employs an algorithm for automatic generation of session keys to support the Perfect Secrecy^{*1}, i.e. a perfect forward secrecy^{*2} against break-backward analyses and/or a perfect backward secrecy against known-key attacks, by information-theoretically isolating the session keys from each other, without relying on computational difficulties.

Background Art

For the IP-layer security of router networks, proposed protocols^{*3} each require a pair of unique encryption and decryption keys for a respective IP datagram.

A solution for the requirement may be such an automatic key generation system that derives a series of pairs of session keys from an original keying material. A respective derived pair is employable to generate a sequence of pairs of encryption and decryption keys for an extensive use of the original keying material, with a problem that a compromised secrecy of a session key permits an access to past, used keys and future, yet unused keys.

An IPSEC (Internet Protocol Security) Working Group of the IETF (International Engineering Task Force) has drafted an ISAKMP (Internet Security Association and Key Management Protocol)^{*4} as a framework for key management to support a current IPSEC protocol and a subsequent IPv6 (Internet Protocol version 6), and an Oakley^{*5} as a set of key determination protocols for current use, with a postponed solution to the problem.

The ISAKMP and Oakley support the perfect forward secrecy to a practical extent.

However, in the IP-layer with a mechanism to a standard default algorithm DES(Data Encryption Standard)-CBC(Cipher Block Chaining), a conforming session

key has a reduced security due to cookies transmitted on a net, and a resultant short-term security service calls for a frequent Diffie-Hellman key exchange to an extent that causes a fairly high traffic overhead via out-of-band mechanisms. The performance subjected to high overhead and the security of session keys have a trade-off relationship to each other.

Disclosure of Invention

The present invention has been achieved with such points in view.

It therefore is an object of the invention to provide an IP key management mechanism, in which the conventional trade-off relationship is eliminated, permitting a long-term security service of an original keying material, supporting the Perfect Secrecy of session keys, providing an IP-Inline security service free from frequent interruptions via out-of-band mechanisms.

To achieve the object, according to an aspect of the invention, there is provided a key management mechanism comprising an IP-key for entering a closed IP network, a key generator for generating from the IP-key a set of session keys indexed for identification, the set of session keys having a "divergence" barrier incorporated therein for barring a computational approach to an arbitrary session key, an index pointer for pointing an index to identify a session key, and an unbar data set for unbaring the divergence barrier.

According to the aspect of the invention, a key management mechanism includes an IP key, a key generator, and an index pointer. The IP key is for entering a closed IP network. The key generator is responsive to the IP key, to generate a set of session keys employable in the network. Session keys in the generated key set are each indexed for identification, and the index pointer points an index to identify a session key used or to be used in the network, permitting a voluntary key selection to be independent of an order of key generation.

One may fetch a used session key, and try a computational approach therefrom in either or both of forward and backward senses of a temporal direction of the key selection, i.e., toward any session key that may be a past, used key or a future, yet unused key.

However, the key set has an always effective "divergence" barrier, i.e. a "bi-directional or universal divergent nature" as a barrier, incorporated therein for barring the computational approach, whether the approach is forward and/or backward with respect to the temporal direction of the key selection which may be wholly or partially identical to or different from the order of key generation.

Any such approach should have a practical limit, so along as it is computational. On the contrary, the barring divergence can be a voluntary setting in a mathematical field, which can by far over-range the computational limit with ease, with a sufficient allowance to absorb or eliminate the conventional trade-off relationship, permitting a long-term security service of the keying material, supporting the Perfect Secrecy of session keys, providing an IP-inline security service free from frequent interruptions via out-of-band mechanisms.

In this respect, the key management mechanism further comprises an unbar data set as a set of data for unbarring the divergence barrier, unveiling the set of session keys to associated peers, allowing the IP-inline security service for the peers.

Preferably, an arbitrary pair of session keys in the key set may be information-theoretically isolated from each other by a drop of information therebetween having a corresponding entropy difference, and the divergence barrier may develop as an integrated entropy difference along a way of the computational approach. The key generator can have a huge key space for generation of session key sets, and each key set generated can have a sufficient size for the entropy integration to diverge beyond a computationally secure entropy difference. The drop of information makes even a theoretical approach for unique solution unsuccessful in any way. The unbar data set may preferably define the drop of information between the arbitrary pair of session keys. The drop of information may preferably comprise a lost data on either or both of a sign data and a numeral data of a respective session key.

Moreover, the divergence barrier may comprise a tree of candidate keys for the arbitrary session key, the tree of candidate keys may diverge with an increasing number of candidate keys beyond a computationally secure number, as the computational approach makes a way in the key set, and the unbar data set may define a unique candidate key to be the arbitrary session key.

Further, the index pointer may preferably point the index of any session key no more than one time. It is ideal for security to use a current key simply one time. Any session key in the generated key set can be a current key, as it's index always permits a current choice by the index pointer.

Further, part of the unbar data set may preferably be built in an outer IP header as a cleartext and transmitted on networks to a communication peer for a connection-less mission of a key agreement in the IP-layer.

Brief Description of Drawings

The above and further objects and novel features of the present invention will

more fully appear from the following detailed description when the same is read in conjunction with the accompanying drawings, in which:

Fig. 1 is block diagram of a closed IP network;

Fig. 2 is a block diagram of an IP key management mechanism according to an embodiment of the invention;

Fig. 3A is a block diagram describing ISAKMP relationships conforming to an internet draft⁶;

Fig. 3B is a block diagram describing a crypt-algorithm of the IP key management mechanism according to the invention;

Fig. 4 is a diagram illustrating a backward divergent nature of intermediate keys generated by a logistic mapping⁷ in a session key generator of the IP key management mechanism of Fig. 2;

Fig. 5A is a graph of the logistic mapping;

Fig. 5B is a Lorentz plot illustrating keys supporting the Perfect Secrecy;

Fig. 6 is a flow chart of actions of the IP key management mechanism of Fig. 2;

Fig. 7 is a data format for a tunnel-mode encapsulating security payload implementing the IP key management mechanism of Fig. 2 to make actions of Fig. 6; and

Fig. 8 is a data format for an outer IP header.

Best Mode for Carrying Out the Invention

There will be described an IP key management mechanism according to an embodiment of the invention, with reference to the accompanying drawings. Like components are designated by like reference characters.

Figs. 1 and 2 show a closed IP network 1 and an IP-inline key management mechanism 10 according to an embodiment of the invention, respectively.

The closed IP network 1 includes: a first internal network 2 having a first group of personal computers as communication peers 2a; a second internal network 3 having a second group of personal computers as communication peers 3a; and an internet 4 communicating via a first router 5 with the first network 2 and via a second router 6 with the second network 3.

The IP-inline key management mechanism 10 has:

an IP key 11 as a data to be manually keyed for peers 2a and 3a to enter the closed IP network 1;

first equipment 50 furnished to the first router 5, including a first "session key automatic generator" (hereafter called "SKGn") 51 responsive to the IP key 11 to

generate a first sequence of I key boxes 52 each indexed for identification by a corresponding index i, each key box 52 containing a first sequence of J session keys 53 each indexed for identification by a corresponding index j, and control programs therefor;

second equipment 60 furnished to the second router 6, including a second SKGn 61 identical to the first SKGn 51 and responsive to the IP key 11 to generate a second sequence of I key boxes 62 each indexed for identification by a corresponding index i, each key box 62 containing a second sequence of J session keys 63 each indexed for identification by a corresponding index j, and control programs therefor; and

a communication system 70 including a first index pointer 71 for controlling a first combination (i,j) of the indices i and j at the first router end, a second index pointer 72 for controlling a second combination (i,j) of the indices i and j at the second router end, and a set of programmed implements 73 for connection-less communications for IP security ESP (encapsulating security payload) and AH (authentication), from a source peer 2a via the internet 4 to a destination peer 3a (or vice versa), ensuring that the first and second index combinations (i,j) are identical to each other. The first and second index pointers 71, 72 each comprise a combination of a first or second i-pointer and a first or second j-pointer for independently pointing the indices i and j, respectively.

Fig. 3A shows a crypt-algorithm in conformity with an internet draft⁶, in which:

an application layer 80 having an application process based on an application protocol is linked with a socket layer of a communication hierarchy 90 including the socket layer, a transport layer (TCP [transmission control protocol], UDP [user datagram protocol]), an IP layer and a link layer; and

an ISAKMP 100 linked with the socket layer cooperates with a DOI definition 101 and a key exchange definition 102 to provide a short-term key via an API (application programming interface) 103 for a security protocol 104 covering AH and ESP and linked with the link layer. The ISAKMP 100 and associated elements are responsible for key establishment, i.e. key generation and transport, and constitute an out-of-band mechanism relative to session keys.

This algorithm supports a perfect forward secrecy at the sacrifice of performance causing a fairly high overhead.

Fig. 3B shows, in comparison with Fig. 3A, a crypt-algorithm for the IP-inline key management mechanism 10 of Fig. 2, in which the mechanism 10 linked with an IP layer has a long-term key based on a manual keying of the IP key 11, and supports an overhead-free Perfect Secrecy as will be seen from the following description. Manual

keying is supported, as required³.

Each session key generator SKG_n 51, 61 of Fig. 2 generates the I key boxes 52, 62 of J session keys 53, 63 by partially overlapped or separated three portions, sections or steps (hereafter collectively called "step"), as follows.

At a first step, the SKG_n responds to an input data [X₀ of Fig. 4] of the IP key 11 to temporally sequentially generate a set of "intermediate keys having a backward divergent nature as a barrier incorporated therein for supporting a perfect forward secrecy" (hereafter called "forward-barrier keys [X_n of Figs. 4 and 5A]").

At a second step, the SKG_n responds to the forward-barrier keys to generate a set of temporally sequential "intermediate keys having a forward divergent nature as a barrier incorporated therein for supporting a perfect backward secrecy, in addition to the backward divergent nature for the perfect forward secrecy" (hereafter called "perfect-barrier keys [sX_n of Fig. 5B]").

At a third step, the SKG_n have index combinations (i,j) sequentially allotted to the perfect-barrier keys and recognizes I subsequences of thus indexed perfect-barrier keys to be the key boxes 52, 62 and J indexed perfect-barrier keys therein to be the session keys 53, 63.

More specifically, as illustrated by Fig. 4, the session key generator SKG_n is adapted at the first step to generate from the IP-key X₀ a set {X_n} of unique forward-barrier keys X_n, by way of a logistic mapping (see Fig. 5A) such that: $X_n = 4 X_{n-1} (1 - X_{n-1})$, where $0 < X_n < 1$, and n is an arbitrary integer.

The logistic mapping allows a trace-back operation from an arbitrary forward-barrier key X_n to an antecedent forward-barrier key X_{n-1}, such that $X_{n-1} = \{1 \pm \sqrt{1 - X_n}\}$, which gives a pair of equally suspicious candidate keys: Y1 (= $1 + \sqrt{1 - X_n}$) and Y2 (= $1 - \sqrt{1 - X_n}$) for the antecedent key X_{n-1}, with an uncertainty of 1 bit to be (+) or (-). Therefore, the trace-back operation between the forward-barrier keys X_{n-1} and X_n is barred with the uncertainty, which constitutes an entropy difference of 1 bit that corresponds to a drop of information on whether (+) or (-).

In other words, a respective pair of neighboring forward-barrier keys X_{n-1} and X_n are information-theoretically isolated in a backward direction by an entropy difference of 1 bit, which gives a backward divergent nature to the key pair X_{n-1} and X_n, which nature appears in the form of a backward divergent tree of candidate keys, constituting a forward-barrier for barring a trace-back operation in the key pair X_{n-1} and X_n.

Therefore, an arbitrary pair of forward-barrier keys X_{n-p} and X_n ($0 < p \leq n$) are isolated in the backward direction by an entropy difference of p bits equivalent to an

integration or sum of intervening p entropy differences, which gives a backward divergent nature to the key pair X_{n-p} and X_n , which nature appears as a p -times diverged backward divergent tree of 2^p candidate keys (like $Y_1, Y_2, Y_3, Y_4, \dots, Y_i, Y_j, Y_k, Y_m, \dots$ in Fig. 4), and constitutes a forward-barrier for barring a trace-back approach between X_{n-p} and X_n . The forward-barrier supports a perfect forward secrecy, as p is increased.

At the second step, the session key generator SKG_n is adapted for a shift operation on a respective forward-barrier key X_n , to drop a total of s ($s > 0$) leading digits of the forward-barrier key X_n , to provide a shifted barrier key sX_n as a corresponding perfect-barrier key.

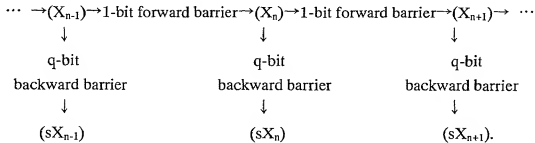
For example, letting $s = 4$, and a concerned forward-barrier key X_n be such that:

$X_n = 856735210183838734956321..$ in decimal notation,
its leading 4 digits '8567' are dropped to provide a corresponding perfect-barrier key sX_n , such that: $sX_n = 35210183838734956321..$ in decimal notation.

Therefore, any reverse-shift operation from the perfect-barrier key sX_n to the forward-barrier key X_n is subjected to a total of 10^s (10^4 in this case) equally suspicious solutions. This uncertainty constitutes an entropy difference of q bits ($12 < q < 13$ for $s = 4$), which directionally acts as a backward barrier for barring the reverse-shift operation between the barrier keys X_n and sX_n .

An antecedent forward-barrier key X_{n-1} is likewise shifted to an antecedent perfect-barrier key sX_{n-1} . Between these barrier keys X_{n-1} and sX_{n-1} also, there is an entropy difference of q bits acting as a directional backward barrier for barring a reverse-shift operation therebetween.

Like this, there is generated a set of perfect-barrier keys $\{sX_n\}$, such that:



As each effective q -bit backward barrier is additive to any effective 1-bit forward barrier, an arbitrary perfect-barrier key sX_n is information-theoretically isolated (as in Fig. 5B) by an entropy difference of q bits along a route $(sX_{n-1} \rightarrow X_{n-1} \rightarrow X_n \rightarrow sX_n)$.

from an antecedent perfect-barrier key sX_{n-1} , and by an entropy difference of $q+1$ bits along a route $(sX_n \leftarrow X_n \leftarrow X_{n+1} \leftarrow sX_{n+1})$ from a subsequent perfect-barrier key sX_{n+1} . With respect to an r -th ($r > 0$) subsequent perfect-barrier key sX_{n+r} , the isolation enlarges as r increments. Along a direct route $(sX_n \leftarrow sX_{n+1} \leftarrow \dots \leftarrow sX_{n+r-1} \leftarrow sX_{n+r})$, the isolation appears as an entropy difference of $(q+1) * r$ bits, exceeding $(12 * r + r)$ bits for $s = 4$.

Like this, an arbitrary pair of perfect-barrier keys sX_n and sX_{n+r} are bi-directionally isolated from each other by entropy differences to be integrated along associated routes therebetween. The bi-directional isolation gives a bi-directional or universal divergent nature to the key pair sX_n and sX_{n+r} , which nature appears as a bi-directionally divergent tree of candidate keys, constituting a bi-directional barrier for barring any computational approach, to support the Perfect Secrecy.

At the third step, all perfect-barrier keys $\{sX_n\}$ are arrayed to be sequentially identified in a forward or reverse direction by combinations (i, j) of discrete or apparently sequential indices i and j , and recognized as a set of $I * J$ session keys 53 or 63 contained in I key boxes 52, 62. Then, simply an arbitrary i -th key box 52, 62 is pointed by the index pointer 71, 72, to be registered for use.

Fig. 6 describes a flow of actions of the IP-inline key management mechanism 10, in which $I = 200$, $J = 512$, $s = 4$, and X_0 = an integer from a field of random numbers having an entropy of 64 digits in decimal notation. Figs. 7 and 8 show formats for a tunnel-mode ESP and an outer IP header.

At a step S1, a data X_0 of the IP key 11 is manually entered, and input to each SKGn 51, 61.

At a step S2, each SKGn generates a set of forward-barrier keys $\{X_n\}$.

At a step S3, each SKGn generates a set of perfect-barrier keys $\{sX_n\}$, identifies $I * J$ perfect-barrier keys by labeling with indices i and j , and recognizes them as a set of $I * J$ sequential session keys 53, 63 divided in subsets and placed in I key boxes 52, 62 in memories.

At a step S4, with the first i -pointer = B (default = 200 in this case), a pointed key box (hereafter referred as "key box (B)") 52 is left in a memory region, while the remaining key boxes 52 are abandoned. The key box (B) has J session keys 53 for selection by the first j -pointer under control of programs.

At a step S5, as the j -pointer is operated at the first router end, there is provided a defined unbar data $(B, j [= K \text{ in Step S6}])$, which will be informed in a later-described manner to the second router end, where it will be processed for the second pointer 72 to identify a corresponding session key (B, j) in the sequence of $I * J$ session keys 63. The unbar data (B, j) is thus cooperative with the session keys (i, j) 63 to constitute an

unbar data set for unbarring the divergence barrier.

At a step S6, the operated j-pointer designates $j = K$ (to be 1 at first), and a pointed session key (B, K) is selected for encryption.

At a step S7, a random flicker is read, which is a random number of 8 digits in decimal notation. As the session key (B, K) has 64 digits in decimal notation, the random flicker is small enough, in information quantity, to provide a relatively secure cookie.

At a step S8, the selected session key (B, K) is modified with the random flicker, to provide a nonce key for one-time use. The random flicker thus constitutes part of the unbar data set.

At a step S9, a transform is performed by using a stream cipher. The transform is what is used to secure the communication channel. For the stream cipher, an engine produces a sequence of binary bits having as high entropy as the nonce key.

At a step S10, an inner IP packet encrypted at the step S9 is carried in accordance with a tunnel-mode ESP payload format of Fig. 7. A combination of the steps S5 to S10 is responsible for one ESP to be processed in milliseconds.

At a step S11, the first j-pointer increments in a forward indexing manner, such that $j=j+1$ (i.e. $K = K+1$), to support a perfect forward secrecy. The flow again goes to step S5 along Loop-j.

At a step S12, after $j = J$, the first j-pointer again goes to $j = 1$, so long as one-time security is effectively held.

At a step S13, as the key box (B) is fully used, the i-pointer decrements in a backward indexing manner, such that $i = i-1$ (i.e. $B = B-1$), to support the perfect backward secrecy against known-key attacks. The flow again goes to step S5 along Loop-i.

After $i = 1$ or while $B > 0$, the flow again goes to step S1.

Incidentally, as to Step S1, the integer X_0 (IP key 11) may be stored as a data in a 3.5-inch disk or IC (integrated circuit) card, to be read therefrom.

In connection with Step S5, the key box (B) has a divergence barrier incorporated therein as an entropy barrier, which is intrinsic in barrier key generation by SKGn itself, and needs an unbar data set as vital crypt-information for unbarring the divergence barrier. In a sense, the unbar data set comprises a sequence of key boxes, and a sequence of index combinations (i, j) for identifying a sequence of unique session keys in the sequence of key-boxes, and a combination of i-pointer and j-pointer constitutes a deterministic crypt-data for opening a key box (B), which data however is stored as a cleartext in a memory. Communication peers 2a, 3a must share the unbar

data set for a key agreement, for which a communication medium is necessary and provided in the form a tunnel-mode ESP payload format as in Fig. 7. This shows that the index pointers are unencrypted, and never occupy part of an inner IP header, but parts of an outer IP header (Fig. 8) as a cleartext, which allows for communication peers 2a, 3a to successfully commit a key agreement in connection-less communication. A third party may access to the crypt-data with ease, and may try crypt-analyses thereon, but will only be left trying for an exhaustive search in the filed of 10^{64} keys. The current proposal^{*6} requires an originator to control SA's (security associations) of recipients. The present embodiment is different, in which a source peer simply controls an unbar data set of its own site, without having unbar data sets of other sites. Such a simplicity is an epoch-making for router networks as VPN's (virtual private networks), as the IP traffic is a mere connection-less flow from an originator to recipients.

As to Step S7, the random flicker may be designed as a random number carrying event data in its initial value, such as setup date and time at a respective site, and programmed to appear with an even probability in respect of the initial value. Note that random flickers are so randomly initialized at every site as to be independent of the randomness of session keys.

The Step S8 corresponds to an entropy generation system in which a small entropy of a flicker is converted into a large entropy of a nonce key. As the flicker is selected from a group of integers having decimal 8 digits appearing with an even probability to an initial value, the entropy generation system can prepare 10^8 different nonce keys from a session key. Such a nonce key is different by site. The nonce key aims at one-time pad to be shared by communication peers.

At the step S10, the unbar data set ($i=B, j=K$, flicker) is unencrypted but covered with authentication and integrity.

At the step S11, for a respective IP-security ESP, one session key is employed. After encryption of a single datagram, the j -pointer increments by unity. In IP-inline key management mechanism 10, the perfect forward secrecy is supported by virtue of an information-theoretical independency or isolation established between a respective current key and any past, used key. In this connection, each session key has an effective forward barrier and an effective backward barrier, as it is identified in a given set of perfect-barrier keys $\{sX_n\}$ in a thinning manner. Letting t be a thinning interval, a respective pair of neighboring session keys comprise a perfect-barrier key sX_n and another perfect-barrier key sX_{n+t+1} , from which the former sX_n is isolated by an apparent entropy difference of $(q+1) * (t+1)$ bits, exceeding $13 * (t+1)$ bits for $s = 4$.

At the step S12, the effect of one-time security depends on a size of the field of nonce keys that is $J(=512) * 10^8$. As respective sites have their random timings for flicker initialization, an arbitrary site may execute a manual and/or programmed control for limiting the reuse of key box (B) to avoid uneven or inclined probability in flicker selection that may develop with an increased number of times of reuse of session keys.

At the step S13, as the key box (B) is reused to a limit, any site is allowed after abandonment of the box (B) to set up a new key box (B-1). As $i = i-1$ ($=B-1$), the flow goes to the step S5, where it has the new key box (B-1) and an updated unbar data $\{B-1, j [=K]\}$ of own site. This unbar data will be shared in a described manner between communication peers, who will thus share the new key box (B-1). The backward indexing provides a key box of future, unused session keys free from known-key attacks.

The Loop-j has been observed to be competent with an IP security to DES-CBC.

In the current proposal⁶, an out-of-band mechanism 100 is responsible for session key establishment, i.e. key generation and transport. In the embodiment, an in-band mechanism 10 makes it. The current proposal supports a perfect forward secrecy through the out-of-band mechanism. The embodiment supports the Perfect Secrecy at the in-band mechanism. The current proposal controls a short-term key needing a frequent ISAKMP SA update with a fairly high overhead. The embodiment employs an IP key 11 to be set up simply once before subsequent IP-inline actions free of overhead. Ping speed is competent.

The IP-inline key management system 10 has broken through difficulties of the Internet Draft⁶ in which, before a security association can be established, at least one pair of messages need to be exchanged between communication peers. For efficiency, this suggests that ISAKMP setup should be infrequent. However, general principles of key management suggest that individual keys should be used as smaller times as practical and changed as frequently as possible.

According to the embodiment, indexed session keys are information-theoretically isolated from each other by entropy barriers incorporated therein, and prevents a compromise of secrecy on any past, used session key nor future, yet unused session key. The session key is large enough in size to diverge the candidate-key tree beyond a computationally secure number of candidate keys. Therefore, the IP-inline key management mechanism ensures that an original keying material is unconditionally secure, in spite of an automatic key generation.

The session key generator SKGn drops crypt-information to make entropy

barriers in a set of session keys it is generating, and provides an unbar data for use to unbar corresponding entropy barriers in a separately prepared set of like session keys. The dropped information is inaccessible. However, the unbar data is accessible at communication peers, as it simply represents a combination of indices, which can be effective unbar data merely when used for pointing a session key in an identical session key set.

Industrial Applicability

The invention provides VPN's (virtual private networks), whose security services support Perfect Secrecy for session keys in a cost effective manner, and unconditional security for an original keying material, even to a manual keying.

The invention allows a long-term service of the keying material for IP-layer, permitting a manually configured keying to realize a selectively encrypting firewall.

The invention can contribute to a business-to-business tunneling protocol without needing CA's (certificate authorities).

References

- *1: C.E. Shannon, "Communication Theory of Secrecy Systems", Bell Systems Technical Journal, 28 (1949), 665-715.
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- *3: RFC (Recommend for Comment) 1825; RFC 1826; and RFC 1827.
- *4: Draft-ietf-ipsec-isakmp-10.txt, ps/July 3, 1998.
- *5: Draft-ietf-ipsec-oakley-02.txt,
"OAKLEY Key Determination Protocol"; and
Draft-ietf-ipsec-isakmp-oakley-08.txt/June 1998,
"Internet Key Exchange".
- *6: Draft-ietf-ipsec-inline-isakmp-01.txt (March 1997)
- *7: Japanese Patent Application Laid-open Publication No. 9-292978,
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CLAIMS

1. A key management mechanism comprising:

an IP-key for entering a closed IP network;

a key generator for generating from the IP-key a set of session keys indexed for identification, the set of session keys having a divergence barrier incorporated therein for barring a computational approach to an arbitrary session key;

an index pointer for pointing an index to identify a session key; and

an unbar data set for unbaring the divergence barrier.

2. The key management mechanism of claim 1, wherein:

an arbitrary pair of session keys are information-theoretically isolated from each other by a drop of information therebetween having an entropy difference corresponding thereto; and

the divergence barrier develops as an integrated entropy difference along a way of the computational approach.

3. The key management mechanism of claim 2, wherein the unbar data set defines the drop of information between the arbitrary pair of session keys.

4. The key management mechanism of claim 2, wherein the drop of information comprises a lost data on one of a sign data and a numeral data of a respective session key.

5. The key management mechanism of claim 1, wherein:

the divergence barrier comprises a tree of candidate keys for the arbitrary session key; and

the tree of candidate keys diverge with an increasing number of candidate keys beyond a computationally secure number, as the computational approach makes a way.

6. The key management mechanism of claim 5, wherein the unbar data set defines a unique candidate key to be the arbitrary session key.

7. The key management mechanism of claim 1, wherein the unbar data set comprises a regenerated set of session keys, and a sequence of index combinations for identifying a unique session key in the regenerated set of session keys.

8. The key management mechanism of claim 7, wherein:

the regenerated set of session keys comprises a sequence of boxes of session keys; and

a respective index combination comprises a combination of a first index for identifying a unique box of session keys, and a second index for identifying the unique session key in the unique box of session keys.

9. The key management mechanism of claim 1, wherein the index pointer does not point the index of any session key more than one time.

10. The key management mechanism of claim 1, wherein part of the unbar data set is built in an outer IP header and transmitted as a cleartext on the closed IP-
5 network to a communication peer for a connection-less mission of a key agreement in an IP layer of the closed IP network.

ABSTRACT

5 A key generator (51, 61) generates, from an IP-key (11) for entering a closed IP network (1), a set (52, 62) of session keys (53, 63) indexed for identification, an index pointer (71, 72) points an index (i, j) to identify a session key (53, 63), the set (52, 62) of session keys has a divergence barrier incorporated therein for barring a computational approach to any session key (53, 63), and an unbar data set (i, j, 62) unbars the divergence barrier.

FIG. 1

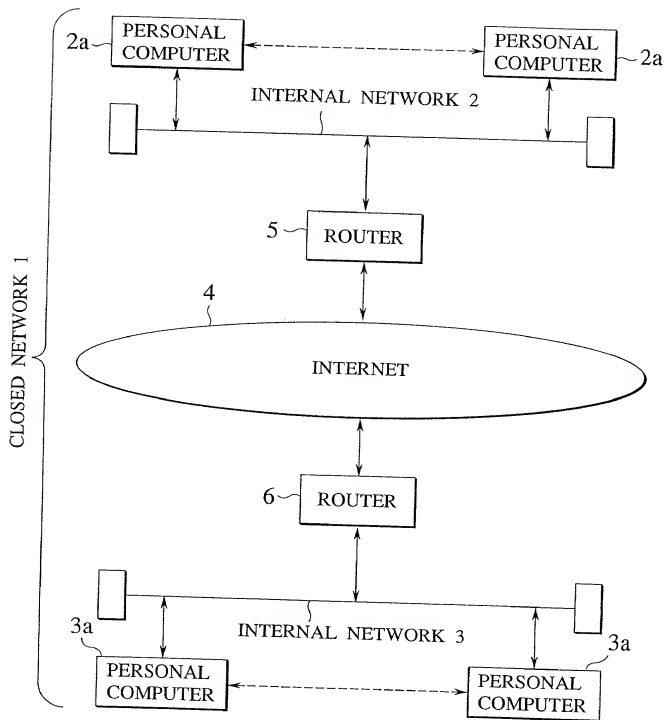


FIG. 2

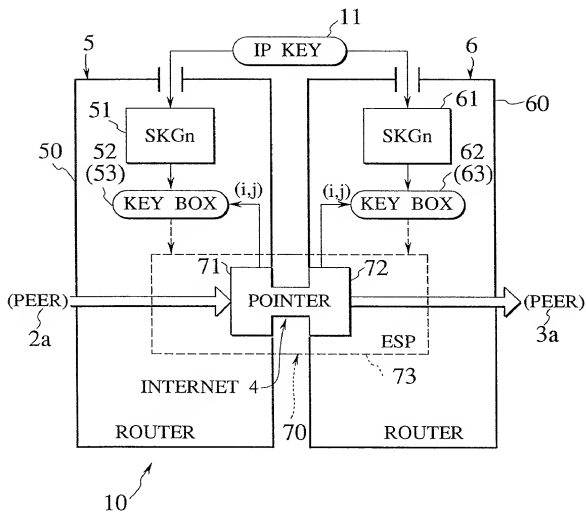


FIG.3A

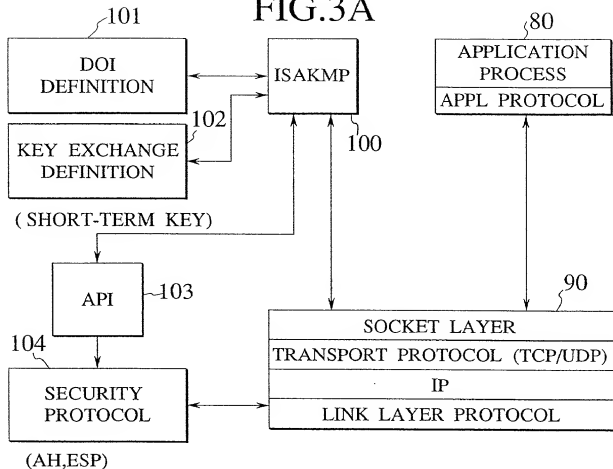


FIG.3B

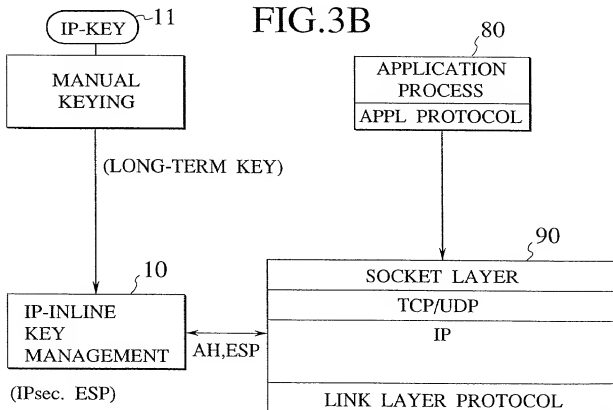


FIG.4

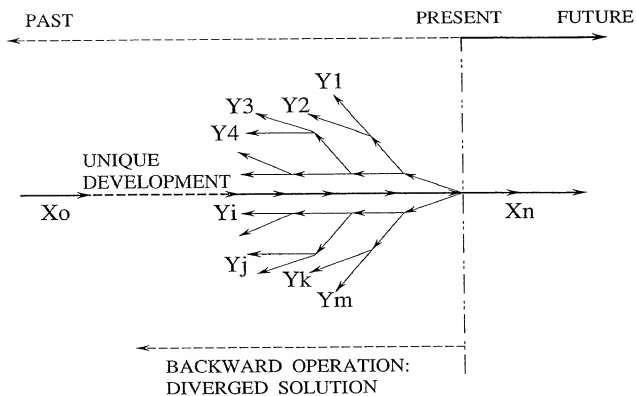


FIG.5A

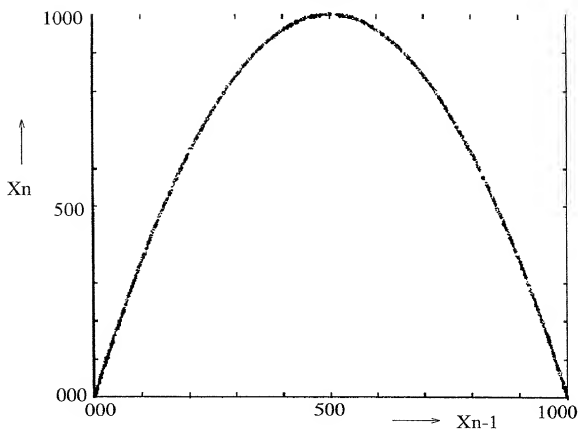
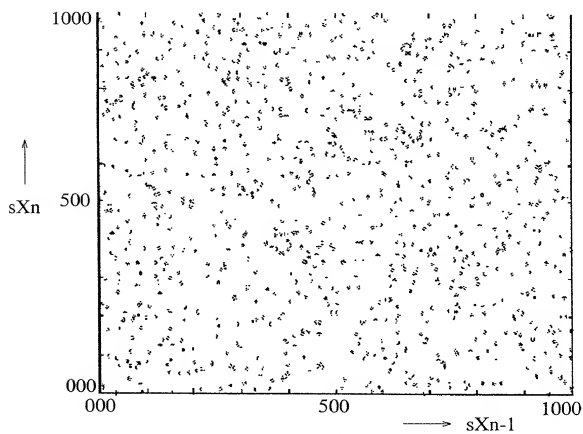


FIG.5B

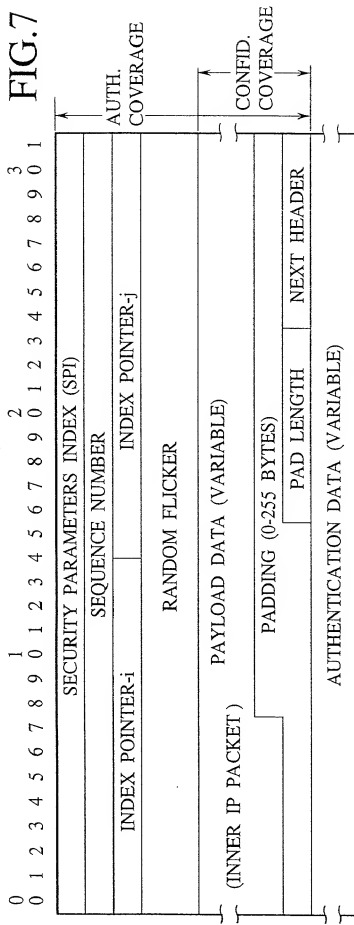


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graph TD
    S1[IP-KEY ENTERING CLOSED NETWORK:X0] --> S2[FORWARD-BARRIER KEY GENERATION BY SKGn(X0)]
    S2 --> S3[SET OF SESSION KEYS WITH ENTROPY BARRIER]
    S3 --> S4[INITIATION OF KEY-BOX(200, j)]
    S4 --> S5[UNBAR DATA SET(i, j, KEY-BOX(i, j))]
    S5 --> S6[SESSION KEY(j) SELECTED]
    S6 --> S7[COOKIE ← RANDOM FLICKER]
    S7 --> S8[NONCE KEY]
    S8 --> S9[TRANSFORM]
    S9 --> S10[TUNNEL-MODE ESP PAYLOAD FORMAT]
    S10 --> S11[PERFECT FORWARD SECRECY]
    S11 --> S12[ONE-TIME SECURITY]
    S12 --> S13[PERFECT BACKWARD SECRECY]
    
    S2 --- Note1["KEYING MATERIAL ≥ DECIMAL  
64-DIGIT ENTROPY  
IN-LINE CRYPTO-ALGORITHM  
RUNS DIRECTLY AT  
IP-LAYER"]
    S3 --- Note2["AUTOMATIC KEY GENERATION"]
    S4 --- Note3["INDEX i, j  
I=200, J=512"]
    S5 --- Note4["512 KEY REGISTERED"]
    S6 --- Note5["CONNECTION-LESS MISSION OF  
KEY AGREEMENT"]
    S7 --- Note6["ONE-TIME KEY VS RANDOM FLICKER"]
    S8 --- Note7["INDEPENDENT OF SESSIONS KEYS  
AND RANDOMLY GENERATED AT  
EVERY SITE"]
    S9 --- Note8["ENTROPY GENERATION SYSTEM  
ONE-TIME PAD"]
    S10 --- Note9["STREAM CIPHER"]
    S11 --- Note10["MEDIUM OF UNBAR DATA  
SET(i, j, FLICKER)"]
    S12 --- Note11["FORWARD INDEXING : j=j+1"]
    S13 --- Note12["USED KEYS INCREASE"]
    
    S5 -- "LOOP-j(j=i+1)" --> S6
    S11 -- "LOOP-i(i=i-1)" --> S5
    
    style Note1 fill:none,stroke:none
    style Note2 fill:none,stroke:none
    style Note3 fill:none,stroke:none
    style Note4 fill:none,stroke:none
    style Note5 fill:none,stroke:none
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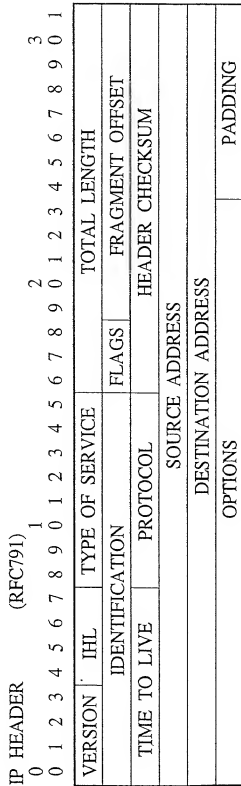
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FIG.7



7/7

FIG.8



Attorney Docket Number: 000004.00616

DECLARATION FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

IP KEY MANAGEMENT MECHANISM WITH DIVERGENCE BARRIER INCREASING ENTROPY AGAINST COMPUTATIONAL CRYPTO-ANALYSES

the specification of which

☒ is attached hereto☐ was filed on _____ as United States Application Number or PCT International Application Number _____ and (if applicable) was amended on _____

I hereby authorize our attorneys to insert the serial number assigned to this application.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR §1.56.

I hereby claim foreign priority benefits under 35 U.S.C. §119(a)-(d) or §365(b) of any foreign application(s) for patent or inventor's certificate, or §365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

PRIOR FOREIGN/PCT APPLICATION(S) AND ANY PRIORITY CLAIMS UNDER 35 USC §119			
APPLICATION NO.	COUNTRY	DAY/MONTH/YEAR FILED	PRIORITY CLAIMED
PCT/JP99/00476 ✓	Japan ✓	04 February 1999 (04.02.99) ✓	

I hereby claim the benefit under 35 U.S.C. §119(e) of any United States provisional application(s) listed below.

PROVISIONAL APPLICATION(S) UNDER 35 U.S.C. §119(e)	
APPLICATION NUMBER	FILING DATE

I hereby claim the benefit under 35 U.S.C. §120 of any United States application, or §365(c) of any PCT International application (designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. §112.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR §1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

PRIOR U.S./PCT INTERNATIONAL APPLICATION(S) DESIGNATED FOR BENEFIT UNDER 35 U.S.C. §120		
APPLICATION NO.	FILING DATE	STATUS — PATENTED, PENDING, ABANDONED

I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected herewith: Herbert Cohen, Reg. No. 25,109; Victor M. Wigman, Reg. No. 25,201; George C. Myers, Jr., Reg. No. 27,040; Donald R. Greene, Reg. No. 22,470; Michael C. Greenbaum, Reg. No. 28,419; Charles R. Wolfe, Jr., Reg. No. 28,680; Michael D. White, Reg. No. 32,795; Karl O. Neidert, Reg. No. 39,313; David J. Edmondson, Reg. No. 35,126; Denise C. Lane, Reg. No. 42,780; Peter Weissman, Reg. No. 40,220; Nicholas Brimmer, Reg. No. 33,478 and Rafael Perez, Reg. No. 46,641.

Declaration for Patent Application (Continued)

000004.00616

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that wilful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such wilful false statements may jeopardize the validity of the application or any patent issued thereon.

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Declaration for Patent Application (Continued)

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